SICE Annual Conference 2012
August 20-23, 2012, Akita University, Akita, Japan

Development of Portable Device of Airborne Ultrasound Tactile Display

Takayuki Hoshi

The Center for Fostering Young and Innovative Researchers, Nagoya Institute of Technology, Aichi, Japan
(Tel : +81-52-735-7446; E-mail: star@nitech.ac.jp)

Abstract: This paper reports the development of a portable device of the ultrasound-based noncontact tactile display. The device is small (19×19×5 cm^3), light (0.6 kg), and compact so that one can pick it up with one hand and install it at various places. This easy-to-use device is expected to lead to a wide variety of application of the tactile display, which is not necessarily related to tactile sensation but, for example, installation arts and measurements.

Keywords: Noncontact tactile display, Integration, Ultrasound, Acoustic radiation pressure.

1. INTRODUCTION

Our research group has worked on a tactile display which produces tactile stimulation from a distance. The tactile display utilizes airborne ultrasound to stimulate the human skin and it is named as Airborne Ultrasound Tactile Display (AUTD) [1]. The ultrasound focused on the skin surface pushes the skin in the direction of propagation. One of the most strengths of the AUTD is that it is noncontact and hence users do not need to wear or have stimulating devices on their hand. Furthermore, the spatial and the temporal resolutions are high and so various patterns of tactile feelings can be reproduced. The maximum output force is several-dozen mN.

The reported applications of the AUTD are as follows. It can add tactile feedback to aerial images [2] and aerial interaction systems [3]. Its ability of fine movement of the stimulation is applied to reproduction of hand-writing motion [4] and remote measurement of compliance [5]. Furthermore, not only our research group, other researchers have tried to utilize the AUTD for their purposes, too. Ciglar proposes to use it as a musical instrument with tactile feedback [6]. Alexander et al. combine the AUTD with a mobile TV [7]. Marshall et al. demonstrate an interactive table on which tangible objects are freely moved [8]. These researches indicate that the AUTD has a diverse possibility of application.

The previously reported devices of the AUTD are space-consuming and heavy. It is because a vast amount of circuits and wirings are needed to control hundreds of ultrasound transducers individually and the master-slave structure is adopted for extensibility of the system. Because of this drawback, people who are not familiar to electronics cannot give it a try to use these devices and the application area has not been widely expanded. It is expected that more people can use it easily for wider variety of applications if the device becomes smaller, lighter, and more compact.

A portable device of AUTD (Fig.1) is introduced in this paper. It is more integrated than the devices previously reported in [3] and [9]. It is 19×19×5 cm^3 and one can pick it up with one hand. Firstly, the principles of the AUTD are outlined in Section 2. Secondly, the developed prototype is described in Section 3. Thirdly, possible applications of the portable device are discussed in Section 4. Finally, Section 5 concludes this paper.

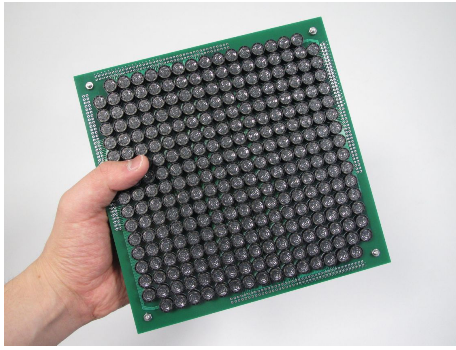

Fig.1 Developed portable AUTD (19×19×5 cm^3).

2. PRINCIPLES

Here the principles of the AUTD are introduced; Acoustic radiation pressure and phased array focusing.

2.1 Acoustic radiation pressure

The acoustic radiation pressure, which is a nonlinear phenomenon of ultrasound, is utilized to stimulate the human skin in midair. When the ultrasound beam is reflected vertically at an object surface, the surface is subjected to the constant vertical force in the direction of the incident beam. Assuming a plane wave, the acoustic radiation pressure P [Pa] is described as

$$P = \alpha E = \alpha \frac{p^2}{\rho c^2} \tag{1}$$

where E [J/m^3] is the energy density of ultrasound, c [m/s] is the sound speed, p [Pa] is the RMS sound pressure of ultrasound, and ρ [kg/m^3] is the density of medium. α is the constant depending on the reflection coefficient at an object surface and α is nearly equal to 2 in the case of the human skin. Eq. (1) suggests that the spatial distribution of the radiation pressure P can be controlled by synthesizing the spatial distribution of the ultrasound p.

2.2 Phased array focusing

The phased array focusing technique is used to produce the radiation pressure perceivable by human skins. The focal point of ultrasound is generated by setting adequate phase delays of multiple transducers. In addition, the focal point can be moved to an arbitrary position by controlling the phase delays.

It is theoretically derived that the spatial distribution of ultrasound generated from a rectangular transducer array is nearly sinc-function shaped [1]. The width of the main lobe (w [m]) parallel to the side of the rectangular is written as

$$w = \frac{2\lambda R}{D} \tag{2}$$

where λ [m] is the wavelength, R [m] is the focal length, and D [m] is the side length of the rectangular array. Eq. (2) indicates that the spatial resolution and the array size are in the relationship of trade-off.

3. PROTOTYPE

A prototype is developed. Description of the new device is followed by comparison between the new and the previous devices.

3.1 Description

The developed portable device (Fig.1) consists of two circuit boards. One is an array board of ultrasound transducers and the other is a controller board including an FPGA and amplifiers. Both boards are 19×19 cm^2. They are connected electrically to each other by pin connectors instead of wirings.

On the array board, 285 ultrasound transducers (T4010A1, Nippon Ceramic Co. Ltd.) are arranged in a rectangular area whose D is 17 cm. As shown in (2), D is related to the resulting size of the focal point. The resonant frequency of the transducers is 40 kHz (i.e. λ = 8.5 mm). Then, w is 20 mm when R is set at 20 cm.

On the controller board, a USB module, an FPGA, and 72 four-channel push-pull drivers (L293DD, STMicroelectronics) are mounted. The operating frequency of the FPGA is 50 MHz. It communicates with a PC via USB interface, calculates the phase delays of all the transducers based on the distance between the target position and the transducers, and generates 40-kHz rectangular waves. The waves are amplified by the drivers and drive the transducers after their DC components are cut by HPFs.

Here how to control the phase and amplitude in the prototype is described. One cycle of 40-kHz rectangular wave is divided into 16 segments (i.e. 1.5625 μs). The phase is controlled by the position of a HIGH (= 24 V) period within the 16 segments, and the amplitude by the duration of the HIGH period. That is, the phase and amplitude are quantized in 4 and 3 bit, respectively.

3.2 Comparison

The simplicity of the system is given priority over the extensibility. The number of the driving circuits (called as slaves) is variable by cascading them in the previous devices in which the master-slave structure is adopted (Fig.2, upper). Differently, in the new device, there is a single driving circuit and the number is not variable (Fig.2, lower).

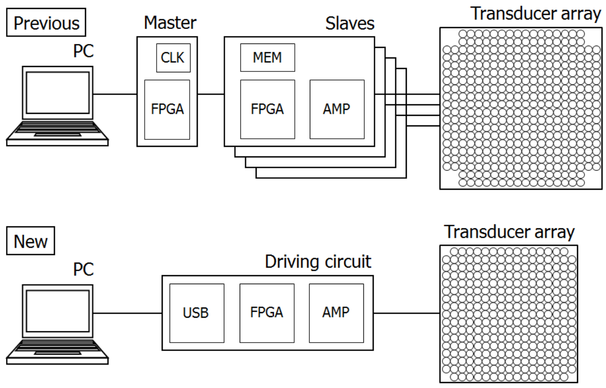

Fig.2 Brock diagrams of previous and new devices.

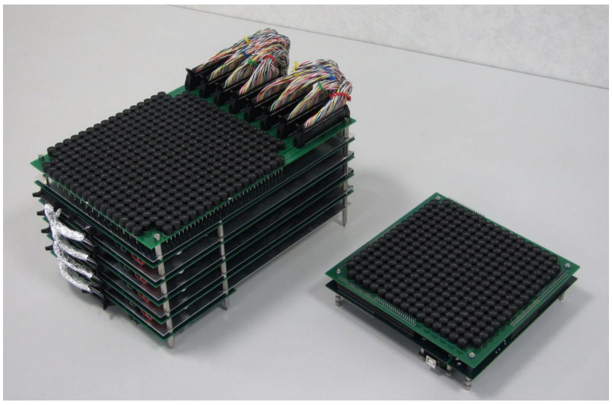

Fig.3 Photo of previous (left) and new (right) devices.

The specifications of the previous [3] and new devices (Fig.3) are listed in Table 1. The new device is about one fifths of the previous one in volume. The miniaturization is achieved mainly by disusing flash memories and decreasing FPGAs. The number of transducers of the new device is less than the previous one according to the number of I/O pins of the FPGA.

4. POSSIBLE APPLICATIONS

Possible applications of the portable AUTD are listed below. We also expect that many other applications are worked up by people who get an opportunity to use it.

4.1 Tactile feedback

The AUTD is suitable to be combined with aerial image displays [2] and aerial interface systems [3] because it provides noncontact tactile feedback. The stimulation of the AUTD moves finely (sub-mm resolution) and so it can reproduce handwriting strokes as tactile stimulation [4]. This kind of tactile stimulation may be utilized for transmitting non-verbal information, giving passwords more safely than displaying them on a screen, and showing characters instead of braille.

Table 1 Specifications of previous and new devices.

	Previous	New
Transducer	384 pcs	285 pcs
Size	29×20×15 cm^3	19×19×5 cm^3
Weight	3.2 kg	0.6 kg
Phase data	Stored in flash memories	Calculated by FPGA in real time
PC interface	Digital I/O PC card	USB
Inter-board connection	Wirings	Pin connectors
Output force	18 mN	Not-yet-measured

Once the portable AUTD is launched, people can easily give it a try to add midair tactile feedback to their 3D vision and/or NUI systems. The portable AUTD can be leased and it is ready when only the USB and the power cables are connected.

4.2 Experiments on tactile sensation

It is expected that new finds are obtained from experiments on the human tactile sensation with the AUTD. The vibrotactile stimulators previously used in the experiments on frequency characteristics of the human tactile sensation are displacement-controlled while the tactile stimulation generated by the AUTD is pressure-controlled. In the displacement-controlled setup, the energy of the vibration is in proportion to the square of the frequency and there are the periods when the stimulator loses contact with the skin [10]. Differently, with the AUTD, the energy is constant with different frequencies and the contact is not lost because of the focal length of the focused ultrasound.

4.3 Installation arts

The AUTD also has possibility to be used in the field of installation arts. The output force is several dozen mN and so it can operates soft and/or light objects such as water, smoke, paper, particles [8], bubbles, balloons, etc. from a distance. Mysterious and attractive effects would be demonstrated by using the AUTD. Furthermore, it could be utilized to “make sound touchable” as demonstrated in [6].

It is easy to install the portable AUTD on the ceiling, the walls, etc. because it is compact. It is even possible to make it wireless if the USB module is replaced with a wireless module (only 10-bit I/O to FPGA is required) and a battery is mounted. This is optional and depends on user’s electronic skill.

4.4 Measurements

The AUTD may contribute to develop a new measurement method in which the material surface is deformed or vibrated. It is used to deform the surface of elastic material and the deformation is measured by a laser displacement sensor to obtain the compliance distribution [5]. For another example, it is expected that the sound-based static electricity measurement [11] is expanded to 2D scan by employing the AUTD.

5. CONCLUSION

A portable device of an ultrasound-based noncontact tactile display was introduced. It is 19×19×5 cm^3 and easy to pick up, bring, and install anywhere. It is expected that this simple device increases the user population and expands its application area.

The device has just developed as of now. Performance assessment and exploration of application are included in future work.

ACKNOWLEDGEMENT

The author would thank Mr. Keisuke Hasegawa, a Ph.D. student of The University of Tokyo, for his helpful comments.

REFERENCES

[1] T. Hoshi, M. Takahashi, T. Iwamoto, and H. Shinoda: Noncontact Tactile Display Based on Radiation Pressure of Airborne Ultrasound, IEEE Trans. Haptics, vol. 3, no. 3, pp. 155-165, 2010.

[2] T. Hoshi, M. Takahashi, K. Nakatsuma, and H. Shinoda: Touchable Holography, Proc. SIGGRAPH 2009, Emerging Technologies, article no. 23, 2009.

[3] T. Hoshi: Development of Aerial-Input and Aerial-Tactile-Feedback System, Proc. IEEE World Haptics 2011, pp. 569-573, 2011.

[4] T. Hoshi: Handwriting Transmission System Using Noncontact Tactile Display, Proc. IEEE Haptics Symposium 2012, pp. 399-401, 2012.

[5] M. Fujiwara, K. Nakatsuma, M. Takahashi, and H. Shinoda: Remote Measurement of Surface Compliance Distribution Using Ultrasound Radiation Pressure, Proc. IEEE World Haptics 2011, pp. 43-47, 2011.

[6] M. Ciglar: An Ultrasound Based Instrument Generating Audible and Tactile Sound, Proc. International Conference on New Interfaces for Musical Expression (NIME 10), pp. 19-22, 2010.

[7] J. Alexander, M.T. Marshall, and S. Subramanian: Adding Haptic Feedback to Mobile TV, CHI Extended Abstracts 2011, pp. 1975-1980, 2011.

[8] M.T. Marshall, T. Carter, J. Alexander, and S. Subramanian: Ultra-tangibles: Creating Movable Tangible Objects On Interactive Tables, Proc. CHI 2012, pp. 2185-2188, 2012.

[9] M. Takahashi and H. Shinoda: Large Aperture Airborne Ultrasound Tactile Display Using Distributed Array Units, Proc. SICE Annual Conference 2010, pp.359-362, 2010.

[10] J.Z. Wu, R.G. Dong, A.W. Schopper, and W.P. Smutz: Analysis of Skin Deformation Profiles During Sinusoidal Vibration of Fingerpad, Annals of Biomedical Engineering, vol. 31, pp. 867-878, 2003.

[11] K. Kikunaga, K. Nonaka, K. Sakai, and T. Kamohara: Development of Technology for Measuring Static Electricity Using Sound Waves, http://www.aist.go.jp/aist_e/latest_research/2012/20120210/20120210.html, Last accessed on 10 May 2012.